Chapter 4 Clean Coal Technologies

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Introduction

As the largest coal consumer in the world, coal represents as much as 70% over the total primary energy composition in China. Since 1996, due to a serial of measures taken by the Chinese government including the closure of small coal mines, coal consumption in China has been greatly reduced, at least that's what has been reflected by the statistics. According to official data, total energy consumption in China reached its historic high in 1996, up to 1,389 million tce and afterwards started a downturn. In 1999, total energy consumption was 1,301 million tce, which was 6.4% less comparing to 1996. However, one could not draw an accurate conclusion that China is gradually moving away from coal, that China is transforming from coal to other forms of energy by simply looking at the phenomenon that over the recent years energy consumption in China has been decreasing. In fact, the drastic reduction in the coal consumption in China from 1998 to 1999 had been the result of forceful campaigns initiated by the central government, rather than the long-term natural tendency of decreasing coal consumption in total energy consumption. Consequently, those coal mines that had been closed while the government was taking strong measures would most probably resume production once the government polices were relaxed. The author explored this issue in great details in another article (Horii [2001]). That's because small coal mines were the real forces that had satisfied the energy demand over the past 20 years since the reform and opening up policies were adopted in China. The market advantages enjoyed by small coal mines have not been changed at all. It could be well justified to say that the reduction in the coal consumption over the past few years in China is nothing but a temporary phenomenon and it will by no means continue for a long term[1]

[1] Further more, the negative growth in the energy consumption from 1996-1999 was not brought about by economic slowdown in China. Although comparing to the first half of the 1999s, the economic growth in the second half of the 1990s was somewhat slowed a bit, the average annual GDP growth still exceeded 7%. Consequently, if we look at the elasticity ratio between energy consumption and GDP growth, we could see a consecutive negative growth in the energy consumption, which is an abnormal phenomenon. Based upon the above, some people might feel doubtful as to the reliability of the statistics that showed reduction in the energy consumption and some people even believed that in reality there have not been any changes in the energy consumption, or there might have been increases, rather than decreases.

In reality, several government organizations and research institute are re-evaluating the mid to long term energy demand and supply in China, based upon the trend of decreasing coal consumption over the past few years. Even under such a scenario, the estimated volume of coal consumption that has been replaced by other forms of energy only represents a very small part of the expanded energy supply. Based upon the analysis made by various organizations and institutes, the proportion of coal in primary energy structure would drop sharply. By 2020, it would be reduced to below 55%, and by 2050, it would be further reduced to below 43%. However, since the overall energy consumption would be constantly increasing, it is estimated that coal consumption in 2020 would reach 1,485 million ton and by 2050 it would grow to 1,763 million ton. Comparing to 1999, in the next 20 years, coal consumption would grow by 180 million ton and in 50 years it would grow by 460 million ton. Therefore, it will never be the case that coal consumption itself will be reduced

On the other hand, air pollution caused by coal is increasingly more serious. If we take a look at SO_2 emission, which has been the primary pollutant that results in acid rain and other environmental problems, in 1996 when energy consumption reached its peak in China, its SO_2 emission reached 23.28 million ton. In the same year, the SO_2 emission in Japan was only 0.88 million ton. That means, although China's energy consumption was only 1.7 times more than that of Japan, its SO_2 emission was 26.5 times more than that of Japan. In addition, the emission of coal dust in 1996 in China reached 15.52 million ton. Even though the SO_2 and coal dust emission has been on the downturn and in 2000 it was reduced to 19.95 million ton and 11.65 million ton respectively, the volume was still huge. In addition, China's dependence on coal, whose carbon contents are relatively high, also leads to huge greenhouse gas CO_2 emission. China has become the second largest country in the world in terms of greenhouse gas emission, being only next to United States, whose CO_2 emission accounted to 13% of the world total. Coal plays a dominant role in the formation of the above-mentioned pollutants, which accounts to 87%, 60%, 67% and 85%in the formation of SO_2. coal dust, NO_x and CO_2 respectively (Chen, [2001]). Considering the fact that China shall remain to be heavily dependent upon coal in its energy structure, how to utilize coal more efficiently and more cleanly would become an important issue in China.

The other chapters included in this book were devoted to such topics as energy conservation and renewable energies, both of which are technologies to replace coal with other substitutes to resolve air pollution. However, as stated above, according to the estimates, although the proportion of coal in the overall energy consumption will be somewhat reduced, its absolute volume would still be constantly on the rise. Under such a situation, it would be impossible to fundamentally resolve the issue of air pollution in

Based upon the above-mentioned point of view, in this article, the author will discuss the development of clean coal technologies (hereinafter referred to as CCTs) and the prospects of its application in China. As what will be further elaborated later in this article, being a large coal producer and consumer, the development of clean coal technologies have reached a certain level in China. However, the issue lies in the fact that those technologies have not been introduced at all. Therefore, in this article, we will focus on what kind of factors have been obstructing the diffusion of the CCTs and what kind of a system needs to be established in order to eliminate those obstacles.

This article will be composed of the following sections. The first section is a general description of the development of CCTs and its diffusion in China. In this section, the author will compare the various CCTs in China and in other countries. As a result, the comparisons will show that although China has already brought in almost all the CCTs available in the world and its technological levels are on par comparing to the developed countries, there is still a great gap in terms of promotion and widespread application of those technologies in China. The next section will focus on what kind of factors has been affecting the diffusion of CCTs in China. Analysis on the relationship between the technologies, and economic and social factors will be conducted. In the third section, the author will explore what kind of policy support would be needed to promote the application of CCTs in China and put forward some proposals. In the last section, the author will have a look at the future development of CCTs in China.

1.The development of CCTs and its diffusion in China

Under the term CCTs, there are a great variety of different technologies. Basically they could be divided into four categories based upon different technological characteristics.

The first category includes the CCTs that process coal before combustion process, which include washing, briquette, CWM (Coal Water Mixture), etc.

The second category includes the measures taken during the combustion process, which include fluidized bed combustion technology (hereinafter referred to as FBC) and integrated gasification and combined cycle (hereinafter referred to as IGCC), etc.

The third category includes all the measures that lead to chemical reaction in coal under high temperature and pressure or by the use of catalyst to change the characteristics of coal itself, including gasification and liquefaction technologies.

The fourth category includes measures that prevent pollution after the combustion process though the so-called pipe-end equipment, including flue gas dust precipitation facilities, de-sulfurization facilities and de-nitrification facilities. In a broader view, the disposal of coal ash after combustion and the environmental protection measures taken by the coal fields are also included in this category.

As stated above, there are a great variety of technologies included in CCTs, although the maturity levels and application scope of those technologies vary from one to another. Next, let's analyze the development and diffusion of different categories of the CCTs in China at this moment as well as their future prospects.

1.1 Coal processing technologies before combustion process

1.1.1 Coal washing

After excavation, in addition to the part that have been coalified, within coal there are also parts such as gangue that does not combust. From the point of view of transportation or heating value, those parts that have no utilization value should be eliminated. Furthermore, if the ash content in coal is too high, coal ash would attach to the inner walls of the boiler during combustion process and in severe cases, it might lead to major explosions. Therefore, it is necessary to process coal by coal washing in order to keep the quality of coal stabilized. In the developed countries, coal washing technologies have reached mature stage and the diffusion rate of coal washing has exceeded 65%. In a few countries including Japan, coal washing rate almost reached 100%.

Coal preparation itself has a long history and there have been many different ways for coal preparation. For instance, there is the so-called manual selection, that is manually sifting coal through a sieve in order to eliminate coal gangues and keep the coal granulate more or less equal in size. Broadly speaking, that is also coal preparation. However, from the sense of clean coal utilization, coal washing methods include jigging method, heavy liquid cyclone method and flotation method, etc. Both jigging and heavy liquid cyclone method basically conduct coal preparation by taking advantage of the nature that the specific gravity of coal and coal gangue is different. More specifically, firstly crash coal into suitable size of granulates (50~100mm), then throw them into such liquid as water or heavy liquid. Shake and gradually coal, which has lighter specific gravity, would float up to the top of the liquid, and coal gangues as well as other heavier substances would sink to the bottom of the liquid. Jigging is done through water, which is a relatively simple process. Coal preparation through heavy liquid could be more refined as it utilizes heavy liquid in which the specific gravity could be adjusted. In addition, centrifugal force could be applied to make coal preparation an even more refined process.

The diffusion of coal washing technologies in China is the following. By 1999, there was 1,585 coal washing factories each with an annual capacity above 30,000 ton and the total processing capacity reached 502.43 million ton. However, as shown in Table 4-1, even in 1999, the actual coal washing volume was only a little bit over 300 million ton, which was only 28.9%[2] of the total coal production volume in China in the same year. It is the general opinion that China has already obtained the necessary technology to build coal washing factories with an annual capacity exceeding 4 million ton. However, in reality, the average annual processing volume in the coal washing factories was only 310,000 ton, of which the average processing capacity of coal washing factories under the state key coal mines was 1.5 million ton and that of coal washing factories under the town and village coal mines was only 70,000 ton. Comparing to the 3.4 million ton average annual processing capacity of coal washing factories in the United States, the figures could well tell the gap between the production scale in China and in the United State (Liu [2001]).

Table 4-1: Designed annual capacity and production of coal washing

Type of coal mines	Designed annual capacity (Mt a^{-1})	washed coal production (Mt)	Percentage of washed coal production to total coal production (%)	Number of coal preparation factories
State key coal mines	354.67	213.95	41.7	237
Local state coal mines	84.29	58.5	27.6	469
Town and village coal mines	63.47	29	9.1	879
Total	502.43	301.45	28.9	1,585

Source: Liu [2001]

[2] This ratio deserves more attention. Due to the implementation of closure policy targeted at small coal mines in 1999, total coal production, which was the denominator of this ratio, had been greatly reduced. It was possible that the reduction in production volume itself had contributed to the artificial increase of coal washing ratio. For instance, the coal washing volume in 1997 was 338.19 million ton, which had exceeded the coal washing volume in 1999. In particular, the coal washing rate in the town and village coal mines in 1997 was 7%. Although the ratio grew to 9.1% in 1999, comparing to the actual coal washing volume in 1997, which was 40 million tons, the coal washing volume in 1999 was only 29 million tons, which showed a decrease in absolute volume. Therefore, even though according to the statistics, the popularization rate of coal washing technologies in China in 1999 reached 28.9%, people might feel that in reality the coal washing rate should have decreased.

Regarding the composition of coal washing methods in China, jigging method accounted to 59%, heavy liquid cyclone method accounted to 23%, flotation method accounted to 14%, and the others accounted to 4%. Since jigging was the predominate method adopted in China, it could be well imagined that the quality of coal washing in China was still rather un-refined. In terms of the quality of coal washing, in the developed countries, the acceptance rate was guaranteed to exceed 95% and in China it was only around 85%. Furthermore, the more severe issue was that although technologically speaking China has reached a certain level, the technologies have not been widely introduced. Based upon the above data it could be reckoned that only 60% of the production capacity of the coal washing factories has been utilized and the other 40% remained idle. In reality, coal washing technologies have only been applied in coking and raw coal has been widely used as fuel without going through the washing process. Later the author will analyze in detail why coal washing technologies have not been widely adopted in China.

1.1.2 briquette method

In terms of combustibility and transportation, it was rather inconvenient to use coal as it was excavated, without any kind of processing. To solve the above problem, briquette method, which is to crash coal first, mix with such additives as bonding agent and de-sulfurization agent, form briquette through pressure, has been proved to be very effective. Based upon different usage, briquette could be classified into industrial briquette and civil briquette, including the so-called honeycomb briquette and egg-shaped briquette.

The advantages of briquette are that after crashing and processing, the combustibility of coal as well as the heating value would be greatly improved. In addition, coal dust and SO_2 emission could be reduced by 40%-60% after adding bonding agent and de-sulfurization agent. In fact, according to several experimental data, since briquette has been applied in industrial boilers in China, the heating value has been improved by 10%-20%, coal consumption has been reduced by 15%-27%, SO_2 emission has been reduced by 52%-73% (Dai and Zhang [2001]). On top of that, briquette also reduces the production costs as it pulverizes and mixes coal and peat, which contains little coke, during the production process and thus utilize low quality coal that otherwise would have been abandoned.

Currently, in urban areas in China, the annual sales volume of briquette coal for residential and service sector use in 2000 has exceeded 50 million ton, which accounted to around 40% of the total coal consumption in civil sector. In the industrial field, although the annual production capacity of briquette coal in China has reached 33 million ton, the sales volume of industrial briquette has been extremely limited. Due to poor sales performances, some briquette enterprises have gone bankrupt. Comparing to the relatively more introduced briquette coal in the residential and service sector use, the development of industrial briquette has been rather stagnant. The primary cause was that the industrial briquette coal was not competitive in terms of prices. For instance, comparing to the raw coal, the price of briquette coal for industrial boilers was RMB 50-70 more expensive. In some areas, such a high processing fee was several times higher than the price of raw coal. Since there has been such a huge price difference, it is understandable that the ordinary consumers would keep away from the briquette coal, although it is more convenient and more efficient. Another cause was that the quality of briquette coal was not very high and it still might fall apart or infiltrate during long transportation even though bondage agents were added.

1.1.3 CWM technology

It was in oil crisis in the 1970s when CWM technology attracted world's attention. Later on, as oil price had been on the downturn, little further researches have been conducted in that area. The so-called CWM technology is to add water and surface active agent and mix it with pulverized coal, increase the affinity of coal particle and water and get coal liquidated. Normally the liquid mixture consists of 65% of coal and 35% of water. Since water represents a significant part in the mixture, the heat value of the mixture per unit measurement is rather low.

CWM technology has many advantages. Speaking of the situation in China, the following advantages of CWM could be pointed out. Firstly, according to the statistics, at the moment, the shrinkage of coal in transportation accounted to 3% of total coal production. In addition, coal transportation also caused remarkable environmental pollution. The application of CWM technology would fundamentally resolve the above two issues. Besides, since water accounts to 35% in the liquid mixture, combustion temperature would be very low, which would suppress the emission of NO_x, although low heat value of CWM was not welcome to users before. If coal that has gone through the washing process, by which sulfur content can be reduced to less than 0.6%, were used as raw material for CWM, comparing to the oil product with the same heat value, the end product equals to oil product that contains less than 1% sulfur content. If de-sulfurization agent were added in the CWM process, the de-sulfurization effect of the end product would be guaranteed to reach 40%-50%. Furthermore, CWM technology proves to be rather effective in energy conservation. We have learned from some public data that 30% of coal consumption could be reduced by transforming coal through CWM technology. By applying CWM technology, the efficiency of small and medium boilers could be increased to 90%, which is 25% higher than coal firing boilers (Zhang [2001]). Table 4-2 shows the CWM projects that have been introduced to China. Of which, most of them were still pilot projects and they were only one step away from being commercialized. According to the operational results in a few power plants including Baiyanghe, Maoming and Shantou, as well as the operational result in Yanshan Petrochemical Factory, heating value reached 98% after replacing coal with CWM, the boiler efficiency could also be guaranteed to reach 90%. Besides, its SO_2 emission equaled to the SO_2 emission of oil with less than 1% sulfur content. The reduced combustion temperature also suppressed the generation of NO_x and comparing to ordinary oil fueled boilers, the NO_x emission of CWM fueled boilers was less than half of that of the former. Over the recent years, China's oil import has been increasing drastically and in 2000, the import of crude oil and oil products reached 70.27 million ton and 18.05 million ton respectively, and the import of crude oil has increased by 91.9% comparing to the previous year. Due to high prices of crude oil in the international market, China's expenses for crude oil import in the same year also increased sharply to 1,486 million US$, which was 2.2 times more than the previous year. It is estimated that by 2010 China's crude oil import would reach 120 million ton and the proportion of domestically produced crude oil would be reduced to 58% (Zhang [2001]). Under such a background, CWM, being an industrial fuel that could basically be handled in the same

Table 4-2: Installed CWM plants in China

Type of users	Name of users	Installed capacity	Year	Notes
Power plants	Shantou Wanfeng heat and power supply company No.2 boiler	50MW/220t/h	2001	
	Maoming heat and power supply company No.1 boiler	50MW/220t/h	2000	Upgraded No.2 boiler coming soon
	Baiyanghe power plant No.1/No.2/No.3 boiler	50MW/230t/h	1999	
	Yanshan Petrochemical Factory	50MW/230t/h	2000	
	Beijing paper No. 1 mill	60t/h heat supply and power boiler	2986	
		20t/h	1984	
		35t/h	1992	
	Bayi coal mine	4t/h industrial boiler	1998	
Industrial boiler	Shengli oil field	10t/h heat supply boiler	1994	Around 10 boilers (7-14MW) are now under upgrade.
		14MW boiler	2000	
	Datong Huihai CWM plant	3MW CWM boiler	2001	
	Daqing city	10t/h	2001	
	Changchun lagging materials plant	Tunnel dry kiln	1989	
	Guilin steal maker	Rolling heat boiler	1990	
Coal mines	Laiwu steal maker	Forging heat boiler	1990	
	Zhuzhou coal washing plant	Heat boiler	1990	
	Fujian Jinjiang	Ceramics dry boiler	2000	

Souce: Zhang [2001]

way as oil, has attracted lots of attention in China.

1.2 High-efficiency coal combustion technologies

1.2.1 FBC

At the time being, fluidized bed combustion (FBC) technologies, particularly the circulated fluidized bed combustion technology (hereinafter referred to as CFBC) has reached mature stage and they are being widely adopted in the world. By nature, it is very convenient to use CFBC boilers and CFBC boilers are widely adaptable to different types of coal with varying quality. In addition, efficiency of CFBC boiler is much higher than that of the ordinary boiler. Its relatively low combustion temperature also greatly reduces NO_X generation. The other advantage of CFBC boiler is that de-sulfurization agents could be added to realize de-sulfurization within the CFBC boiler. Currently, the capacity of the largest CFBC boiler that has been put into operation in the world has reached 700t/h (around 135MW) and CFBC boiler with even larger capacity of 1,500t/h (around 285MW) is currently being designed.

Over the last few years, CFBC boiler technologies have been developing rapidly in China and the technological gap between China and the developed countries is been narrowed. Small CFBC boilers ranging from 35t/h (6MW) to 75t/h (15MW) have been introduced through out China. In terms of numbers, it has been reported that there were over 350 CFBC boilers with the capacity under 75t/h, of which 320 boilers have the capacity of 75t/h. In addition, there were 20 CFBC boilers with the capacity of 220t/h (50MW) and over 10 CFBC boilers with the capacity of 410t/h (75MW) in China. Therefore, the number of CFBC boilers with various capacities in China already ranked the top in the world. Furthermore, The Gaoba Power Plant in Sichuan province has decided to build CFBC boilers with the capacity of 100MW. It shows that the design and development of CFBC boilers in China have reached stage for commercialized production for CFBC boilers with the capacity of 100MW. On top of that, the Baima Power Plant in Sichuan province was preparing to build the largest CFBC boiler ever in the world as a pilot project, with the capacity of 1,025t/h (200MW).

Of the fluidized bed combustion technologies, pressurized fluidized bed combustion technology (hereinafter referred to as PFBC) is still under development. Comparing to CFBC boilers, the combustion efficency of PFBC boilers is even better and could reach 40%. Up until 2001, 8 PFBC boilers have been put into operation in the world and some of them have entered into commercial operations. At the moment, the largest power-generating PFBC boiler in the world is the 360MW boiler in the Karita Power Plant in Japan.

China started researches on PEBC technologies during its 7^{th} five-year plan period (1985-1990). In 1998, which was in the middle of its 8^{th} five-year plan period, Jiawang Power Plant in Jiangsu province started to implement a model PFBC boilers project with the capacity of 15MW and in 2000 had a successfully trial operation. That experimental boiler project was constructed purely with China's domestic technologies. It is reported that China has already brought in large-scale equipment from abroad and would focus on domesticating the imported technologies after digesting and absorbing the foreign technologies.

1.2.2 IGCC technology

The so-called IGCC power generating technology refers to the high-efficiency power generation technology that firstly distributing the gasified coal gas to the gas turbine for power generation and at same time, having the normal steam power generation through exhaust heat recovery. The power generation efficiency of such a technology could reach 45%. Due to the fact that in this technology, gasification of coal, which is the first step, needs a very delicate operation and the whole process is conducted under ultrahigh temperature and ultrahigh pressure. IGCC technology has not reached its mature stage any where in the world, either in terms of durability of the boilers or in other aspects. From 1993 to 2001, only 4 IGCC power plants with the capacity ranging from 250-300MW have been built in the United States and Europe as pilot projects. In the other words, even in developed countries, IGCC technology was still under the experimental stage for commercial operations.

China has just started its initial researches on IGCC technology and there is still a long way to go before it could be actually implemented in power plants. More specifically, China is still focusing on the researches on single equipment including the gasification reactor, pipe, and de-sulfurization of coal gas, etc and it will take a long time before China would reach the stage of combining all the single equipment together for overall designs. Lunan chemical industry group could be taken as one of the few sample cases of coal gasification reactor under operation in China. The group brought in the technology from Texaco, built a coal gasification plant in its Chemical Fertilizer Factory, which has been under operation for a few years already. It was confirmed that during the 9^{th} five-year plan period, China would build an IGCC plant in Yantai city of Shandong province as a pilot project. After a long time delay following the planned starting date, finally Simens and Shell participated in the equipment bidding process. It was planned that the project should be completed and start to generate power in 2005.

1.3 Coal transformation technologies through chemical reaction

1.3.1 Coal gasification

Coal gasification is conducted based upon the principles of thermal decomposition, partial oxidization, and hydrogenate decomposition. As to which method should be adopted, it mainly depends upon which kind of end gas product was needed. For instance, the primary objective of thermal decomposition is coking, and gas is only a byproduct. In terms of hydrogenate decomposition technologies, currently the United States is developing such technologies as high gas method and high drain method, etc. However, up until now, none of them seem to have reached stage for commercial application. Therefore, generally speaking, partial oxidization has been the most widely adopted gasification technology across the world in applying IGCC technologies for power generation.

Oxygen (or air) and steam is used for partial oxidization of coal. More specifically, the process is as follows. Have part of coal combust and the temperature within the furnace reach a high level, if necessary add pressure to reach higher pressure[3], gasify coal structure through thermal decomposition. At the same time, the generated solid carbon reacts with oxygen and steam, which results in coal gas with methane as its main component. Great caution is needed during the whole process, particularly in controlling the temperature, as hydrogen is generated during the chemical reaction and there is great danger of explosion.

Although the coal gasification technology has not reached its mature stage, it has attracted widespread attention, as it has many advantages including its environmentally friendliness. More specifically, de-sulfurization and de-nitrification could be conducted during the gasification process. In addition, since it is a kind of gas energy, there is no coal dust emission in actual utilization, neither is there the need for coal ash disposal after the combustion process in end users level. Therefore, coal gasification technology is very helpful in controlling the emission of pollutants. Texaco, Dow and Shell are the leading companies in the world in this field. Of the three companies, Texaco started the commercialization of coal gasification in the 1980s and Shell has been following its lead. However, due to the sharp decrease of natural gas prices in the whole 1980s, although

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[3] If the moving bed Lurgi furnace is adopted as the reactor, there would be higher pressure ranging from 25-35 within the furnace and the gasification reaction would occur when the temperature reaches 600 800 . If bubbling bed Kobbas-Tochek furnace is adopted as the reactor, the reaction process would be conducted under normal air pressure with the temperature of around 1400 . If the fluidized bed Winkler furnace is adopted as the reactor, the reaction process is conducted by gasifying coal granulates with the diameter of around 5mm under the temperature of around 1000 .

the researches on coal gasification was still on going, there is a long way to go before it could be commercialized.

As to the situation in China, fixed bed reactors have been built in many places that generate gas through the reactions amongst coal, oxygen and steam under normal air pressure. However, the efficiency of such gasification reactors has been rather low[4] and the density of methane in the resulting gas is also very low. Undeniably, the technology in China in developing gasification reactors lacks behind that of the world advanced technologies by scores of years. Based upon different applications, coal gas could be classified into chemical raw material, industrial and residential fuel. Next, let's have a look at each application in China (Xu, [2001]). First let's have a look at the situation in which coal gas was applied as the chemical raw material. According to earlier statistics, in 1994, of the 900 small to medium sized fertilizer factories in China, there were altogether 4,000 old-fashioned fixed bed gasification reactors that operated under constant pressure. On top of that, there were a few Winkler reactors in some places in Jilin province, a few Kobbas -Tochek reactors in Xinjiang province and a few Lurgi reactors in Yunan province. As to coal gas applied as industrial fuel, it was reported that there were a total number of around 4,000 gasification reactors in metallurgy, machinery, construction material, light industry and food processing industries. In contrast to coal gas applied in the above two sectors, coal gas for civil use in urban areas has been growing rapidly. Of gas used by urban residents for daily life, coal gas, LPG and natural gas each took around one third of the total market. In the past, coal gas mainly resulted from thermal decomposition as a byproduct during the coking process. Over the recent few years, the number of fixed bed gasification reactors has been on the rise. Furthermore, more than 10 Lurgi reactors have been built in Harbin in Heilongjiang, Lanzhou in Gansu and Yima in Henan province.

1.3.2 Coal liquefaction

There are two types of coal liquefaction technologies: the direct liquefaction and indirect liquefaction. The so-called direct liquefaction is the method that directly transforms solid coal into liquid fuel, which is normally conducted through hydrogen decomposition under high temperature and high pressure. Hydrogen decomposition is conducted by using catalyst or by adding dissolvent that causes hydrogen reaction during the thermal decomposition process. Within a period of time after the oil crisis occurred in the 1970s, the researches on direct liquefaction of coal had greatly advanced. However, following the continued stagnation of oil prices since the 1980s, up until now,

[4] In fact, it takes only a few minutes to generate gas through the fluidized bed rector, and only a few seconds to generate gas through the bubbling bed reactor. However, it will take several hours to generate gas through fixed bed reactor.

the direct coal liquefaction technologies have not reached the stage for commercialization yet. The indirect liquefaction technology refers to the process of first gasifying and transforming coal into synthetic gas, which is composed of carbon monoxide and hydrogen, and then adds catalyst for chemical reaction, which generates synthetic hydrocarbon oil. Currently, in South Africa this technology is applied for mass industrial production and the annual production volume exceeded 7 million tons. However, the resulting liquid fuel is mainly composed of paraffin hydrocarbon, and although that is suitable to be used as diesel oil, it has the drawback that the octane value of the remaining gasoline is too low. To solve this problem, in the 1970s the technology of producing methanol by utilizing synthetic coal and then produce high-octane value gasoline by utilizing methanol was developed. The drawback of this technology was that it needed two working procedures to get the end product from synthetic coal gas. Currently, some companies are working on technologies that could produce synthetic gasoline through only one procedure. From the commercial point view, comparing to direct liquefaction technology, the indirect liquefaction technology has broader technical prospects. However, due to the fact that the price of the end product is around US$ 35-45 per barrel, which is much higher than the CWM technology, which has been introduced earlier, there is still a long way to go before the indirect liquefaction technology is to be widely applied.

Indirect coal liquefaction technology has been included in the list of the key technology development projects in China's 6th and 7th five-year plans. It is the general opinion that China has reached advanced level in terms of direct liquefaction technology. Regarding the indirect coal liquefaction technology, it is being developed by the Science Academy of China at the moment. Such products as high-octane value gasoline were being produced on a trial basis with the annual production capacity of 2000 ton. However, except for the influences from the fluctuation of oil prices, it would still take a long time before the indirect coal liquefaction technology could be commercialized in large scale in China.

1.4 Post combustion pollution treatment technologies

1.4.1 Flue gas ash precipitation technology

The biggest difference between coal and other forms of fuel such as natural gas and oil is that coal generates a great deal of ash after combustion. Being a form of solid fuel, lots of ash particles resulted from coal combustion would be discharged into the air together with flue gas. Therefore, it is necessary to eliminate ash from flue gas through certain pipe-end technologies.

Almost all the power plants in the developed countries in the world including Japan have been equipped with electrostatic precipitators or bug filter type precipitators. As a result, the precipitation efficiency of those power plants could reach as high as 99.9%. Furthermore, those technologies are not very complicated, and the cost in bringing in those technologies is much lower than flue gas de-sulfurization technology, which would be discussed later.

Although both electrostatic precipitator and bug filter type precipitator technologies have been introduced to a certain degree in China, the other technologies such as water-film type precipitator technology were still deep-rooted and they were mainly applied in small to medium sized power plants and small industrial boilers. We will discuss those technologies in further detail later. The designed precipitation efficiency of water-film type precipitator technology was 80% or even lower and in actual operation, however, the precipitation efficiency is much lower than the designed level due to poor management.

1.4.2 Flue gas de-sulfurizationflue technologies

Flue gas de-sulfurization technologies include the dry type method that applies solid absorbent (activated coke, limestone and MO_3) and the wet type method that applies water solution absorbent (slaked lime slurry and alkali solution). The above absorbents react with flue gas and disintegrate SO_2 through gypsum or sulfuric acid for separate recovery.

In the developed countries, wet type method de-sulfurization facilities have been installed in around 95% of the power plants, where coal was consumed in large volumes. For the medium and small boilers, de-sulfurization was normally realized by simply adding slaked lime into the furnaces. In terms of de-sulfurization efficiency, wet type method could reach 90%-99% and dry type method could reach 70%-90%.

Up until 1998, only 10 sets of de-sulfurization facilities were constructed in China, of which, half were installed in industrial boilers and the other half were installed in power plants. Six of the de-sulfurization facilities were built with the financial support from Japan's Green Aid Plan and the other four were built with the financial support from other countries including Germany. It is planned that another five sets of de-sulfurization facilities would be constructed. Table 4-3 shows the lists of the de-sulfurization facilities that have been put into operation and the de-sulfurization facilities that have been planned for construction in China. The Table shows that except for a few projects, most of the projects were constructed with soft loans or grants support from abroad. Apparently China has not established an appropriate financing system and environment necessary for the construction of flue gas de-sulfurization facilities, for which huge investments were needed. It is also except for Baima Power Plant, all the other equipment had been produced by Japanese manufacturers including MHI, EBARA, IVO International and Steinmuller.

Table 4-3: Power plant flue gas de-sulfurization projects in China

Power Plant	*Location*	*Technology Supplier*	*Boiler Capacity (MW)*	*FGD Capacity MW*	*Estimated FGD Cost $75 per kw*	*Financing ($millions) Domestic*	*Financing ($millions) Foreign*	*Financing Terms*	*Financing Year*
Baima Power Plant	Sichuan	Ministry of Electric Power	1/4 x 200	50	3.8	1.1	-	Chinese Gov't grant	1990
Luohuang Phase I	Chongqing	Mitsubishi Heavy Industry	2 x 360	720	54.0	26.0	28.0	Japan Export Credit	1989
Huangdao Power Plant	Shandong	Mitsubishi Heavy Industry	1/3 x 210	69.3	5.2	–	35.0	Japan Grant- 100%	1993
Xiaguan Power Plant	Jiangsu	IVO International, Ltd.	2 x 125	250	18.8	12.3	6.5	Finland Grant- 100%	1993
Dezhou Heat and Power	Shandong	Alanco Environmental	1/3 x 125	41	3.1	3.1	0.0	Dezhou power plant	
Taiyuan First Thermal Plant	Shanxi	Babcock-Hitachi	2/3 x 300	198	14.9	–	35.0	Japan Grant- 100%	1995
Luohuang Phase II	Chongqing	Mitsubishi Heavy Industry	2 x 360	720	54.0	41.7	12.3	Japan Export credit 10 yr/ 6.97%	1996
Chengdu Power Plant	Sichuan	Ebara Corporation	1 x 200	200	15.0	2.1	12.9	Ebara Corp. Grant - 100%	1996
Ma Wang Power Plant	Shenzhen	ABB (Norway)	1 x 300	300	22.5	25.0	-	Const. & Commercial Bank of China	1997
Chongqing Power Plant	Chongqing	Steinmueller	2 x 200	400	30.0	–	34.0	German Soft loan - 84% grant	1997
Banshan Power Plant	Zhejiang	Steinmueller	2 x 125	250	18.8	–	31.7	German Soft loan - 84% grant	1997
Beijing 1st Power Plant	Beijing	Steinmueller	2 x 100	200	15.0	–	30.0	German Soft loan - 84% grant	1997
Qianqing Power Plant	Zhejiang	IVO International, Ltd.	1 x 125	125	9.4	6.0	–	Domestic financing	1998
Liuzhou Power Plant	Guangxi	–	2 x 200	400	30.0		39.0	Japan Soft loan - 40% grant	1996
Hancheng Power Plant	Shaanxi	–	2 x 600	1200	90.0		90.0	Japan Soft loan	1996
Shi Dong Kou Power Plant	Shanghai	–	2 x 300	600	45.0		80.0	Japan Export Credit (untied); 20 year; 5 year grace	1998
Shajiao A	Guandong	–	1 x 300	300	22.5		–	Domestic financing	1999
				6,023	$451.7	$117.2	$434.4		

Source: Compiled by Peter Evans, MIT, 1999

It is clear that the development of de-sulfurization facilities in China is still in the stage of pilot projects. The flue gas de-sulfurization technology itself has been standardized and there are no technical barriers in promoting this technology in China. At the same time, China is also developing low cost, unsophisticated de-sulfurization facilities by itself, whose designed de-sulfurization efficiency is around 60% -70%. However, in reality, owing to cost constraints, little progress has been made in promoting de-sulfurization facilities in China. Of course, it does not make any sense to attribute the problem to high cost alone, because de-sulfurization facilities have been introduced to a certain extent in the developed countries. Later we will discusse why de-sulfurization technologies have not been widely applied in China.

1.4.3 Flue gas de-nitrification technology

NO_x is generated while nitrogen contained in fuel and nitrogen contained in air react with oxygen. To eliminate nitrogen in the combustion process, such technologies as low NO_x burner, two-stage combustion and flue gas recycle method could be applied. Flue gas de-nitrification method could be applied to eliminate NO_x after combustion process. Generally speaking, improved combustion process could suppress the generation of NO_x, which means to keep the combustion temperature on a lower level. This method has been more widely applied since the cost of this method is rather low. In countries like Japan and Germany where the air pollution standard is very high, flue gas de-nitrification facilities have been widely applied. There are also two types of flue gas de-nitrification technology: wet type method and dry type method. Of the latter, selective contact reduction method applied in the dry type method is most practical, which utilizes catalyst under the temperature condition of 250-400degree, add ammonia to selectively restore NO_x in flue gas into nitrogen and water. Through this process, the de-nitrification efficiency could reach 80%-90%, which is much higher than the 30%-60% de-nitrification efficiency that could be obtained by improving the combustion. However, the cost of the former is also much higher than the latter, as the former is scores or even hundreds times more expensive.

In China it is mandatory that relevant de-nitrification equipment must be installed in all boilers with the capacity above 300MW to reduce NO_x emission during the combustion process. Therefore, de-nitrification facilities have basically been introduced for large capacity boilers. However, regarding boilers with the capacity below 300MW, no measures have been taken yet. Up until now, China has not installed any flue gas de-nitrification facilities yet.

1.5 Evaluation on the application of CCTs in China and the existing problems

In conclusion, in terms of CCTs, almost all kinds of CCTs have been applied to varying degrees in China. Even in comparison to advanced international level, China's domestic CCTs have reached a certain level, although they are not exactly on par with the developed countries yet. In particular, China has established a sound technical basis for such mature technologies as coal washing, briquette, CWM, CFBC, and flue gas dust precipitation de-sulfurization technologies. However, there is still a long way to go before those technologies could be introduced in China. The application of coal washing and de-sulfurization facilities could best show the situation in China. Let's start with coal washing technology. Currently, only 60% of the total capacity of coal washing factories have been utilized in each year and the other 40% of the production capacity remained idle. Although the coal washing technology has been introduced and the production capacity itself has been growing each year, the production of washed coal remained stagnant. Such a fact shows that it is the economic or social factors that have obstructed the diffusion of CCTs in China, rather than the technical factors. As to de-sulfurization facilities, up until now, almost all the projects on de-sulfurization that have been put into operation had been built with foreign financial support and none of them was constructed as a normal commercial project. Like coal washing technology, de-sulfurization technology has also been standardized. As it has often been pointed out that to a large extent, high cost has been the major obstacle in promoting the de-sulfurization technology, which is quite true. However, from another perspective, the cost for coal washing is not so high. As one of the major components in managing coal quality, coal users should be well justified to demand coal mines to conduct coal washing. Therefore, it would be an arbitrary conclusion to say that CCTs have not been widely applied in China simply because of the high costs. If coal washing technology could be introduced in the developed countries, at least it shows that in the developed countries there exists a mechanism that helps to absorb the unfavorable cost factors, and in China, there is no such a mechanism in place yet.

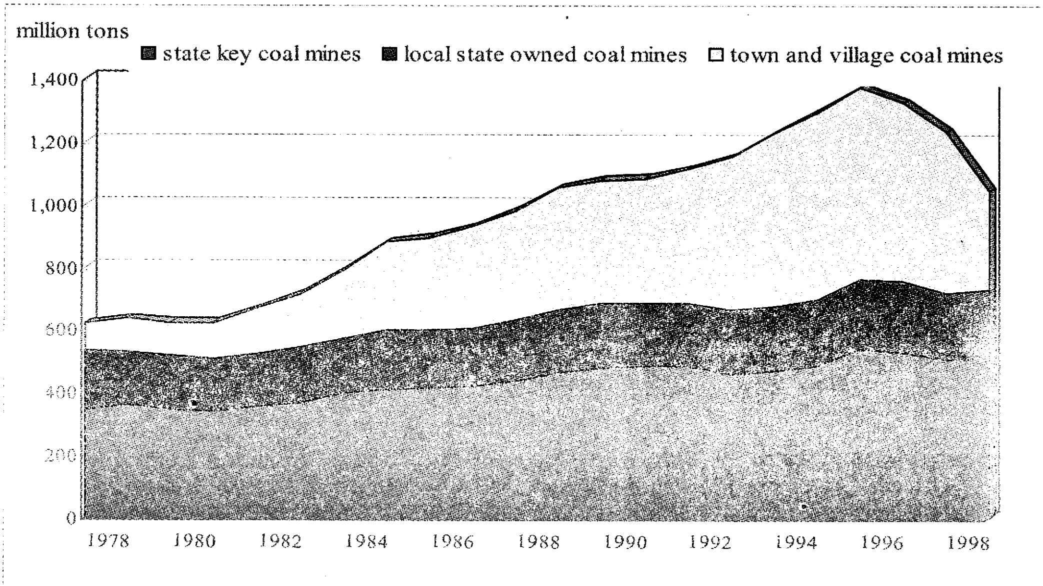
2. Analysis on the existing barriers to the deployment of the CCTs in China based upon the current coal distribution

Without analyzing China's actual coal distribution, it would not be easy to clearly see why CCTs are not widely adopted in China. The reason is that, in addition to high cost, there are many other factors that affected the diffusion of CCTs. Next, let's have a look at current China's coal distribution in more detail and discuss what factors impede the

2.1 Coal production structure

Figure 4-1 shows the changes in the coal output volume during the period of reform and opening up in different type coal mines. We could see that town and village coal mines had taken the position that was once held by the state key coal mines, which were called the centralized allocation coal mines before 1993. At that time the output of the State key coal mines accounted to 55.3% of the national total. The output of town and village coal mines has been growing by large margins. In 1996, when the output of town and village coal mines reached its peak, the output of State key coal mines were reduced to 39.1% of the national total. In great contrast, the output of town and village coal mines grew from 14.1% in 1978 to 44.7% in 1996. There was no exaggeration to say that to a large degree, the expanded production volume of town and village coal mines satisfied most of the energy demand increase that was brought about by the economic growth during the reform and opening up period. During the mean time, the production volume of the state key coal mines and local state owned coal mines stagnated. In other words, the status of the State key coal mines that had played a major role in supplying coal in the planned economy period had been reduced and town and village coal mines had taken up the leading position and made great contributions to the coal production.

Figure 4-1: Coal production development in different type coal mines



Source: *China Coal Industry Yearbook*, each version.

What is the significance of the tremendous development of the town and village coal mines? Let's have a closer look at this issue.

Coal mines in China could be basically categorized into 3 groups shown in Figure 4-2.

Such categories are mainly based upon their ownership structures. However, as stated above, their differences were not only limited to ownership structures. Each group also had different coal distribution channels. The first group was the state key coal mines that had played a major role under the planned economic system. Coal mines in this group were normally invested and managed by the central government. In the past, their products were also allocated by the central government. The second group was the local state owned coal mines under the management of provincial or county governments. The third group was generally called town and village coal mines invested and managed by the town and village governments or individuals. Town and village coal mines were normally established in rural areas. As shown in the chart, there were over 70,000 town and village coal mines in 1995. Town and village coal mines mainly were small coal mines with an average annual production less than 1% of that of the state key coal mines. Therefore, when town and village coal mines replaced the major position held by the state key coal mines during the reform and opening up period, it represented the growth in the output of the small coal mines.

Figure 4-2: Three categories of China's coal mines

- **State key coal mines** — 596 mines
  Avg. Prod.: 738 thousands ton
- **Local state owned coal mines**
  Avg. Prod.: 109 thousands ton
  - Province owned — 203 mines
  - District owned — 390 mines
  - County owned — 1,210 mines
- **Town village mines** — 72,919 mines
  Avg. Prod.: 7.9 thousands ton

Note: "Avg. Prod." represents average per-mine production per year.
Source: prepared by author based on *China Coal Industry Yearbook 1998*, 1995 data.

Such a growth in the output of small coal mines deserves our special attention as since the 1980s, the major coal-producing countries in the world went through the process of increased share of coal production by large coal mines and the elimination of small coal mines. No wonder people were surprised to find that in China, which is the largest coal-producing country in the world, the output of small coal mines could reach almost half of the national output. As shown in Table 4-4, China's coal industry ranks the top in terms of both fatality rate and employee number. The average annual coal output of each coal mine was only 16,300 tons, which was lower than that of South Africa, Germany output was only 5% of that of India's.

Table 4-4: Basic indicators of major coal producing countries

	coal production (Mt)	number of death by accident (persons)	fatal rates (persons/Mt)	labor force (thousands persons)	labor productivity (ton/person)	average annual production per a mine (thousands tons)
USA	936.9	47	0.05	105.5	8872.0	367.8
Japan	6.3	2	0.32	2.6	2401.0	485.9
Australia	242.8	-	-	25.5	7560.8	-
Germany	246.4	-	-	92.6	574.5	2794.7
South Africa	203.5	47	0.23	62.1	3319.1	3329
Poland	198.8	34	0.25	275.0	491.6	2032.8
Russia	262.2	217	0.82	585.5	435.5	535.2
India	285.5	137	0.54	641.1	461.0	233.2
China	1360.7	6,761	5.23	7638.0	169.2	16.3

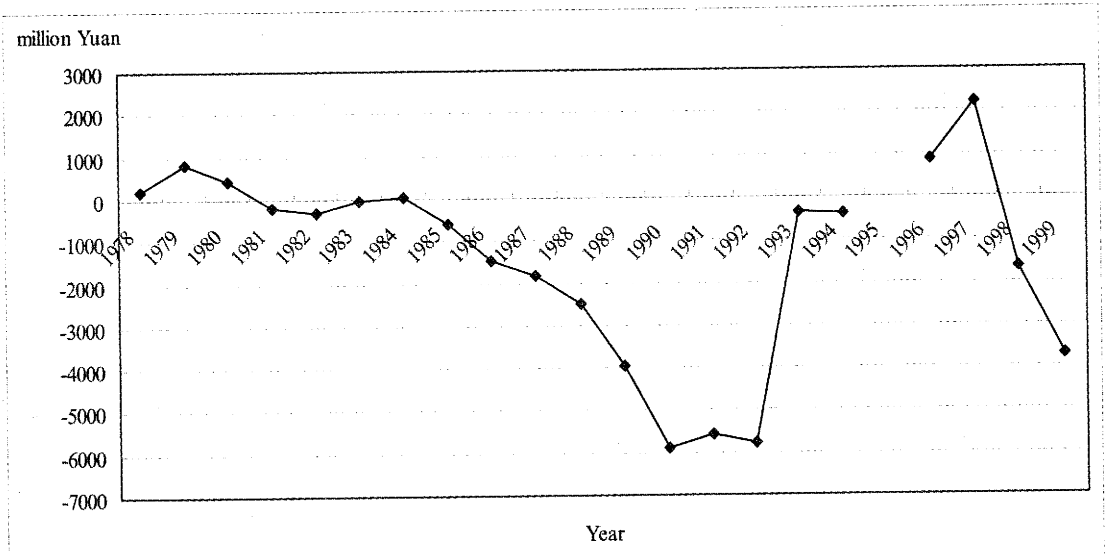
Notes: 1995 data, except for South Africa with 1996 and Russia with 1997.

Source: prepared by author based upon Li [1998] and other source,

The development of the market economy greatly benefited the growth of the town and village coal mines (Horii [2000]; Horii [2001]). In 1979, when the reform was first put on the agenda, severe energy shortages had been part of the daily life in China. Under such a backdrop, apparently it was not possible to rely upon the existing energy supply system to satisfy the growing energy demand that had been brought about along with the implementation of the economic reforms. In fact, Figure 4-3 shows that based upon the operational indexes, since 1978, the state key coal mines had been running at a loss from 1985 to 1994. The state key coal mines had fallen into a vicious cycle: the higher the coal output, the heavier the losses. Many opinions have been put forward regarding the problems faced by the state key coal mines in China, such as the deep-rooted lack of cost concept fostered by the long term planned economic system; huge numbers of redundant staff and various social burdens, etc. (Ma &Gu [1998], pp.8-23). Such problems still remain to be addressed even during the second half of the 1990s.

Under such a situation, in the beginning of 1980s, the central government adopted measures to encourage town and village coal mines, which had been on the outskirts of the energy supply system, in order to increase coal production, instead of pushing forward reforms right directly in the state key coal mines. More specifically, the central government delegated the examination and approval authority on the establishment of the new town and village coal mines to the local governments and greatly relaxed restrictions on the operational method, sales target and pricing in town and village coal mines. In addition, the town and village coal mines were also granted certain tax preferential policies. The above measures achieved great results. Based upon statistic figures, the number of town and village coal mines jumped from 17,800 in 1978 to 91,000 in 1989, and hit a historic high. Although later on due to tighter control the number dropped somewhat, there were still more than 70,000 town and village coal mines in 1995. It showed that within a few years time, large numbers of town and village coal mines have successfully participated in the market competition.

Figure 4-3: Profit and deficit of state key coal mines



Note: 1995 data is excluded from figure because its coverage is different from other years'.
Source: prepared by author.

However, the growth trend of the average annual output of coal mines was on the opposite of the growth in the number of coal mines. In 1978, the average annual output was 9,000 tons and by 1985, it had dipped drastically to 3,600 tons. Only by 1989, the average annual output grew a little, and in 1995, it finally restored to 7,900 tons. (Wang [1995], p.179; Ye and Zhang [1998], pp.35-36; Li [1998], pp.98-99)

Based upon the figures related to the number of coal mines and the average annual output of coal mines, it could be concluded that there had been an explosive growth in the number of town and village coal mines, which newly built in the beginning of 1980s. The explosive growth was attributable to the implementation of the deregulation policies. However, most of the new coal mines were very small in scale. That is to say, large numbers of small newly established coal mines contributed to the output growth of town and village coal mines, as shown in Figure 4-1. Although each new coal mine was extremely limited in scale, by accumulating the output of small coal mines the total output was significantly increased. Thus, the coal production structure had shifted from the old structure in the planned economy that focused on the state key coal mines which were built with huge government investments, to the new structure that focused on the small town and village coal mines with extensive coal production.

2.2 Coal consumption structure

During the mean time, the consumption structure of coal was also experiencing great changes during the reform and opening up period. Similar to the growth in the output of small coal mines in the coal production, the demand of small coal users also has grown significantly in the consumption sector.

Let's first have a look at the largest coal consuming sector, the power industry. Table 4-5 shows the statistics of the thermal power plants by scale. From the Table, we could see that since the 1990s, along with the construction of large thermal power plants with capacity over 300 MW, the construction of small thermal power plants with capacity less than 100 MW also continued. Although the percentage of small power plants decreased from 41.3% in 1994 to 37.7% in 1998, the number of small power plants was almost doubled from 1,802 to 3,322. The new ones were mainly the small power plants invested by county and lower level local governments.

Table 4-5: Number of thermal generator units and their total installed capacity by scale

	1990		1995		1998	
	number	installed capacity (MW)	number	installed capacity (MW)	number	installed capacity (MW)
more than 300MW	46	15,070	123	42,075	209	71,337
200MW-300MW	120	24,160	177	35,600	192	38,610
100MW-200MW	187	20,570	250	27,844	299	33,697
50MW-100MW	224	11,361	309	16,050	362	18,704
25MW-50MW	358	9,364	475	13,531	522	14,094
12MW-25MW	502	6,401	761	9,601	843	10,585
6MW-12MW	718	4,645	1,332	9,585	1,595	11,497
less than 6MW	-	10,274	-	11,755	-	13,459

Source: *The almanac of China power* each version, China Power Publishing House.

Since the 1980s, deregulation was also introduced to the power industry. Particularly in 1985, some regulations implemented in the past were greatly deregulated in order to encourage investments in the construction of new power plants. The main reasons were that the financial difficulties of the central government had reached its limits and the government was no longer able to make investments by their own funding to build new power plants. On the other hand, due to severe power shortages, industrial enterprises were forced to only operate partially during a week. Under such a severe situation, the central government delegated the examination and approval authorities on investments made to the power industry to local governments and abolished relevant restrictions (Ministry of Power Industry [1995]).

The other reform that was of greater importance was the reform on the pricing system that had governed the selling price of power to the grid. In the past, since power plants were built with government funding, the selling power price was basically fixed at a level that roughly covered only the operational costs, not covered the construction costs and profits of the power plants. In other words, the power price was extremely low. New pricing policies were introduced for the new power plants built after 1985. The newly built power plants were not only allowed to take into account of the construction costs in its pricing, but also granted freedom in setting up their own running costs based upon the fluctuation of the fuel prices and they could even incorporate certain profits in its pricing. (Liu, Liu and Li [1998], Chapter 2; World Bank [1997], Chapter 5). Consequently, the investors were not only guaranteed on the recovery of their investment, but also were guaranteed to certain amount of profits.

Since investing in power plants became a guaranteed profitable business under the newly introduced pricing system, in many places people surged to make investments in power projects. However, although local government at different levels showed great interests in the power projects, comparing to the large power stations that needed huge investment, they were much more inclined to invest in small power plants due to shortage of funds. Of course, power plants, being the representative of industry heavily dependent upon the equipment they use, the larger the scale, the higher the efficiency would be. Whereas under the new pricing system, small power plants with low efficiency and high operational costs were allowed to transfer all the costs to the prices. In reality, such a policy contributed to the trend that local governments applied their limited funds to the construction of small power plants as early as possible and later tried to recover their investments as quickly as possible. Besides, large power plants not only request huge investment, the investment risks were also higher as the pay back period would be much longer. That was also one of the reasons that few entities on the local level were interested in large power projects.

In conclusion, since the 1980s, the number of small coal users increased as a result of

The power industry was not the only one that contributed to the surge of the number of small coal users as, in the overall coal consumption structure, power industry accounted to 45% over the total. Next to the power sector, industrial or household boilers took up 30% of the total coal supply. As in the power industry, there had been the same trend in the growth of small coal users in the industrial and household boilers.

Table 4-6 shows the changes in the number of industrial and household boilers. We could see that within the past 20 years, the number of industrial and household boilers increased from around 200 thousands units before the 1980s to around 500 thousands units and the total installed capacity also tripled from 370 thousands ton/h to 1, 210 thousands ton/h. However, the growth of the average capacity of each boiler was only marginal – from 1.85 ton/h to 2.42 ton/h and most boilers remained small in scale. It was calculated that in average, such small coal boilers consumed around 700 tons of coal on an annual basis. In other words, over the 20 years, there increased around 300 thousands new coal users, each consumed around 700 tons annually. Their accumulative coal demand alone amounts to 200 million tons annually.

Table 4-6: Number and installed capacity of industrial and household boilers

Before 1980s	the end of 1998
Number of Units	
about 200 thousands	5,000,902 units
Installed capacities	
370 thousands t/h	1,212 thousands t/h
Average capacities	
1.85t/h	2.42t/h

Source: Liu [2000].

To a large degree, the increase in the number of industrial and household boilers was attributable to the implementation of the market oriented economic reforms. Since the state owned enterprises had landed in operational impediments, the town and village enterprises and private enterprises played the role of the locomotive in the economic development during the reform and opening up period. Comparing to the large state owned enterprises that were built under the planned economic, most town and village enterprises and privately owned enterprises were much smaller in size and geologically very scattered. According to the industrial census conducted in 1995, by the end of 1995, there were altogether 6,518,000 town and village enterprises. Of which, regarding the size of the town and village enterprises only 1,832 town and village enterprises were large or medium enterprises, less than 0.03% of the total number. There was a considerable gap between the town and village enterprises and the state owned enterprises as 19.5% of the latter were large or medium sized enterprises. However, those small enterprise groups that scattered in rural areas developed in leaps and bounds during the process of the market oriented reforms and formed the market basis for the development of large numbers of small coal mines.

2.3 The evolution of coal distribution system as a result of the market oriented reforms

As discussed above, along with the transformation from a planned economy to the market economy, the number of small players soured both in the production and consumption. It could be observed that the emergence of the small players was also the result of the multiplier effects in the old coal distribution system under the planned economy. That's because in the coal distribution system under the old planned economic system, the state key coal mines were responsible to provide coal to the large state owned enterprises in accordance to the production plans made by the central government. Similarly, the local state owned coal mines and town and village coal mines were responsible to provide coal to the state owned enterprises managed by local governments, to small enterprises on the town and village level, and to the residents. Such a distribution system was basically maintained even during the 1980s when various deregulation were adopted and the market-oriented reforms were conducted. Due to the above reasons, and through the economic reforms, town and village enterprises and private enterprises became the locomotive of the economic, while the state owned enterprises faced huge difficulties. The growth of the town and village enterprises and private enterprises was closely related to the tremendous development of town and village coal mines that were responsible to provide coal to those new users.

During the last few years of 1980s and the beginning of 1990s, various rules related to the coal distribution system had been changed as many measures initially intended to encourage the development of town and village coal mines also applied to the state owned coal mines gradually. More specifically, in 1984, the restrictions on the pricing of the town and village coal mines were lifted and in 1986, the centralized allocation coal mines were allowed to sell surplus coal products at a higher price, as long as it was less than two times of the government designated selling price. Since 1987, the price fluctuation range was further expanded and different prices such as the government designated prices, the guiding price that doubled the designated price, the directional price that tripled the designated price and the market oriented price coexisted in the market. Starting from July 1 1992, the capping price on the extra-plan coal was finally then, except for coal used by power industry, no other coal allocation plans had been made[5]. Market mechanism was allowed to play its full function.

However, we can find the fact that there still existed a dual distribution structure based upon coal distribution system under the old planned economy. That means the coal from the state key coal mines were distributed to the large state owned enterprises and coal from town and village coal mines were distributed to local small enterprises and to local residents. As shown in Table 4-7, which compared the distribution of state key coal mines and that of the town and village coal mines, 62.5% of the coal output from state key coal mines were distributed to other provinces. Whereas for the town and village coal mines, 57% of the output was consumed within the same the county and only 19.4% was distributed to other provinces. The figures show that the state key coal mines supplied coal to users in more remote areas by the means of long distance transportation and the local enterprises constituted the majority customers to town and village coal mines.

Table 4-7: Difference in coal distribution among different types of mines

	Total production	Volume distributed beyond province	Volume distributed beyond county
State key mines	482 million tons	301 million tons (62.5%)	n.a.
Town-village mines	579 million tons	112 million tons (19.4%)	249 million tons (43.0%)

Source: Calculated by author based upon Li (1998) and *China Coal Industry Yearbook*.

2.4 Impacts on the diffusion of CCTs

As stated above, there are two major characteristics in the current coal distribution structure in China. On the one hand, the proportion of small coal mines in production and the proportion of small coal users in consumption have both been constantly growing, which have been brought about after China adopted the market oriented economic reforms. On the other hand, the market of coal produced by town and village coal mines, which represents nearly half of the total national coal production, has been limited to nearby counties where the town and village coal mines were located. That is a crucial factor to our analysis on the diffusion of CCTs in China. Next, the author would like to point out a few factors that have obstructed the wide application of CCTs in China, based upon the analysis on China's current coal distribution structure.

2.4.1 Lack of investment capability

For small power plants and small coal firing boilers for both industrial and household purposes, a certain amount of investment were needed to implement even those technically mature CCTs, such as CFBC boiler and flue gas dust precipitation and de-sulfurization technology. Apparently it would not be easy for the small users to get return on their investment. For instance, the initial investment needed for a small coal firing boiler was only around 200 to 400 thousands RMB, which is around 25-48 thousands US$. In comparison, the initial investment for a de-sulfurization facility would be as much as tens million US$ and the annual operational cost would be millions US$. The choice would be rather obvious. Even such high-efficiency flue gas dust precipitation facilities as electrostatic precipitator or bug filter type precipitator, whose initial cost ranges from 200 to 1,000 thousands RMB and the annual operational cost would be around RMB 50 to 250 thousands RMB depending on the scale (The State Environmental Protection Bureau [1997] p.43) were not introduced because the costs were too higher compared with total investment for whole plant. Instead, water-film type precipitator facilities with the precipitation efficiency of 80% were widely adopted, which only needed 80 thousands RMB as the initial investment and the annual operational cost was only 50 thousands RMB (The State Environmental Protection Bureau [1997] p.58). Due to the same consideration, up until now, many small power plants still depended upon water-film-type precipitators, although the small power plants have a bigger investment than the small industrial or household boilers.

In fact, it is unrealistic to expect small users that only have limited capacity to make investment in production facilities to invest an equal amount or even bigger amount in pollution prevention facilities. Of course, for the power plants with power grid networks, it was still possible for them to replace and close the small power plants with large power plants[6]. However, for the industrial and household boilers, since each boiler belonged to an independent enterprise, the scale of the boiler equipment would not be expanded, unless the production scale of the enterprise itself was expanded. However, it is not so easy for the enterprises to expand their production scales.

2.4.2 The gap between the current level of the CCTs and the technical requirements in real life

It is mentioned in section 1 that coal washing could not only greatly improve energy efficiency at relatively low cost, it could also help to control ash from the perspective of stabilizing boiler operation, more effectively. Therefore, in some countries including

[6] From 1999-2003, small power plants with the capacity under 100MW would gradually be enforced to shut down. Large power plants with the capacity of 300MW would be constructed for centralized power

Japan and United States; it's the users that demanded coal mines to conduct coal washing. While in China, 40% of the existing capacity of the coal washing factories has not been utilized, let alone increasing the coal washing rate. Such a reality shows that the problem did not lie with the suppliers, instead, on the demand side, the coal users did not actively press the producers for washed coal, and that deserves our attention.

Such a situation is closely related with the fact that there were a large number of small coal users in China. If we have a close look at the statistics on coal washing in different types of coal mines in China, we could see that the coal washing rate in state key coal mines reached 41.7%, and the coal washing rate in town and village coal mines remained at 9.1% (refer to Table 4-1). The figures showed that the customers of town and village coal mines, in most cases the small coal users, did not opt for washed coal. It is certainly not the case that those customers were not aware of the benefits of washed coal. Instead, most small coal users were equipped with the so-called stoker type boilers, for which no high quality coal was needed. Frankly speaking, normal operation of the boilers would be interrupted even if no ash control measures were taken. For instance, 95% of the industrial and household boilers were stoker type boilers, and less than 5% boilers were pulverized coal firing boilers, which requested meticulous operational management. Therefore, the technical backwardness of the users had obstructed the promotion and diffusion of CCTs in China.

2.4.3 Unreasonably low coal price

Since CCTs could greatly contribute to energy conservation and help to reduce the fuel costs, it would be reasonable for the users to actively pursue to apply such technologies. However, in reality, as analyzed earlier, small coal users represented a large proportion in China's coal market and the coal consumption by each user was not very high. Therefore, the reduction in coal consumption through CCTs would not make any major impacts as to the production cost of the enterprises.

The other even more important issue was that raw coal, which was in direct competition with CCTs, has been priced extremely low, which is mainly caused by town and village coal mines' externalities. Table 4-8 compared the price difference between raw coal and various CCTs processed products. From which we could see that the prices of washed coal, briquette, CWM were 78.6%, 59.8% and 42.7-59.0% more expensive than the price of raw coal respectively. Besides, no matter what was the price of raw coal, the CCTs processing costs would remain on a certain level. Consequently, in comparison to the extremely lowly priced raw coal, CCTs processed products would seem to be highly priced anyway.

Table 4-8: Comparison for price difference among different energy source

	Heat Value (MJ kg^{-1})	Price (Yuan/t^{-1})	Price with same heat value (Yuan/t^{-1})
Raw coal	12.09	141	0.0117
Washed coal	12.63	264	0.0209
Briquette	12.09	226	0.0187
CWM	18.84-20.91	350	0.0167-0.0186
Heavy oil	40.98	1,500-1,800	0.0366-0.0439
Natural gas	31.36(MJ/m^3)	1.7(Yuan/m^3)	0.054

Notes: The price of raw coal, washed coal and briquette is that of Henan province in 1999. The other is average data in whole country.

Source: Data on Raw coal, Washed coal and Briquette is calculated by author based on *Henan Statistical Yearbook 2000*. Data on CWM, Heavy oil and Natural gas are based on Li and Zhan [2001]

As stated earlier, it was due to the extremely low price of raw coal that stoker boilers dominated in the small boiler market in China. Since the price of raw coal has been so low, users were not motivated to place the old-fashioned stoker boilers with boilers with higher energy efficiency, since the former needed little investment, even though the energy efficiency was lower. In sharp contrast, in some other countries such as Japan, as energy prices have been high, the enterprises were motivated to upgrade the production equipment as long as the technical renovation could improve the energy efficiency. Consequently, in those countries there has formed a cycle that enterprises constantly made investments on new equipment, which resulted in constant expansion of the production scale.

2.4.4 Lack of scale economy in CCTs investment

The fact that in China, coal distribution was conducted within the small area of the county and neighboring area where small coal mines were located also discouraged the producers in applying CCTs. That's because the producers would need to make investment for the equipment, no matter what type of CCTs they select, such as coal washing, briquette or CWM. To get return on the investment, it was necessary for the producers to reach a certain production scale. However, under the current regionally disintegrated coal distribution structure, it was very difficult for the producers to expand its production to reach scale of economy. Let's take the example of coal washing technology. The statistics showed that the average annual production capacity of coal washing factories under the town and village coal mines was only 70,000 ton, which proved from the suppliers' side that their operational capacity could only support production scale on that level. Under such a situation, it would be out of the question for the producers to make investment on such high-end coal washing facilities like heavy liquid cyclone facility and get return on their investment for the fixed assets.

In fact, the problems were not too severe with such unsophisticated equipment like coal washing and briquette equipment. It would be deadly for the producers to get return on the investment if the production scale of such CCTs like CMW, which needed huge investment for the equipment, could not reach a certain level. Although we have pointed out that easy-for-transportation has been one of the advantages of CWM technologies, due to the fact that there are great numbers of small coal mines in different areas, it would be even more difficult for CWM to compete with locally produced raw coal.

2.4.5 Issues in implementing the environmental restriction measures

From the above analysis, we could see that under the current coal distribution structure, it would be very difficult to promote the application of CCTs in China from the perspective of energy conservation, since the energy conservation results were not enough to drive the diffusion of CCTs. Therefore, the only hope was that the fundamental effect of CCTs, which is pollution prevention, could help to introduce CCTs in China. However, up until now, due to certain problems in implementing the environmental restriction measures, not much tangible results have been achieved so far.

Environmental protection restriction measures include relevant laws and regulations on such air pollutants as coal dust and SO_2, which were directly related to the CCTs. Clear standards have been established regarding the emission of those pollutants. A system that charges fees for excessive emission has also been established. Therefore, under normal circumstances, since CCTs equipment could reduce the emission of pollutants, thus reduces the expenses of the enterprises, there should have been economic incentives in promoting the application of CCTs.

However, the problem was that although relevantly complete laws and regulations on environmental protection have been in place, in reality, those restrictions did not bring about the expected results. Many factors[7] have contributed to the current insufficiency of environmental regulation, and the most important of all was the difficulty in monitoring. The current environmental restrictions were targeted to collect the emission data at coal users level. However, as stated earlier, since the 1980s, the number of coal

[7] For details, please refer to Blackman and Harrington [1999].

exceeded 500 thousands sets in China. It is by no means an easy job to monitor the specific emission of such a huge number of coal users. As a result, the following method to monitor the emission at coal consuming users has been adopted. The coal users were requested to report the quality of coal that they were using. Based upon that, the regulator calculated the emission volume of pollutants based upon certain formulas, which served as the basis in determining the amounts for excessive pollution fees. However, since the self-reporting monitoring system has been adopted, it was possible that the reported quality was higher than the actual situation. In addition, the excessive emission fees were very low, and under the current system, it was not feasible to charge fees that higher and emissions were lower than the actual emission volume. As a result, the environmental restrictions only played a limited role in promoting the application of CCTs in China.

3. Necessary policy framework for the diffusion of CCTs in China

3.1 The principle of the policy support for the diffusion of CCTs

As analyzed earlier in this article, to promote the wide application of CCTs, it is necessary to give full consideration to the existing dual structure of the coal distribution system in China while making policy decisions. The so-called dual structure refers to the fact that on the one hand, there is a coal distribution system from the large and well-equipped coal mines represented by the state key coal mines to the large and mostly state owned enterprises. On the other hand, there is another coal distribution system from the large numbers of so-called small and technologically backward town and village coal mines to the local small coal users. What separates China from the other developed coal producing and consuming countries is that, in China, the latter accounted to over half of the total coal distribution volume. Over the recent few years, Chinese government had initiated a policy campaign to shut down small coal mines represented by town and village coal mines. It is reported that from 1998 to 2001, a total number of 47 thousands coal mines had been forced to shut down and in correspondence to the closure of small coal mines, the coal production was reduced by 350 million ton. However, as analyzed by the author (Horii [2002]), the above mentioned policy did not take into consideration of the dual structure of coal distribution in China. Consequently, it could not solve the fundamental issues related to the formation of the dual distribution structure, such as the insufficient transportation infrastructure and the lack of intermediary functions in the market[8]. Therefore, even if the mandatory closure policy could achieve some short-term results owing to strong initiative by central governmet, it would not be able to play a long-term role. Even from the perspective of coal prices, comparing the prices of coal would not be able to play a long-term role. Even from the perspective of coal prices, comparing the prices of coal supplied by small coal mines and by state key coal mines, in provinces including Shanxi, the prices of the former were only half or even quarter of the latter (Li, [1998], p.100). Since small coal mines enjoyed absolute advantages in the price competition with the state key coal mines, most small coal users, to whom the quality of coal did not matter too much, would certainly prefer coal supplied by small coal mines.

In view of the reality, in formulating the policy support to the promotion of CCTs in China, it is necessary to give full attention to the fact that there was the dual coal distribution structure and based upon that, work out the policy framework. In the previous section, the author has elaborated how did the latter of the dual structure, which was the coal distribution structure from small coal mines to small coal users, affected the diffusion of CCTs in China. However, such a situation would unavoidably affect the application of CCTs in the other primary coal distribution structure, which was from the large coal mines to the large coal users. The reason is that if CCTs were imposed only on the large coal users, it would only result in the unfair competition between the large users and small users, which should be avoided.

In conclusion, the following principles should be considered while formulating the policies aiming at promoting the diffusion of CCTs in China, (1) Create an environment in which the market mechanism could play out its functions in the coal distribution structure, (2) Combine various CCTs based upon the specific situations, (3) The environmental regulations should be based upon the overall coal distribution market, (4) combine the CCTs deployment with the industrial restructuring, which is ongoing at the moment, and obtain the synergy effects, (5) Strengthen the contacts and coordination with the international fund raising mechanisms. Next, we discuss more detail about each principle that has been mentioned here.

3.2 Create an environment in which the market mechanism could play out its functions in the coal distribution structure

As pointed out in the previous section, of the factors that obstructed the diffusion of CCTs in China, extremely low coal pricing has been the major obstacle. In fact, that issue had initiated the closure policy targeted at small coal mines over the recent years. It's the oversupply of coal from town and village coal mines that have resulted in the decline of coal prices. The decreasing coal prices have resulted in operational losses to many state owned coal mines. Consequently, Chinese government implemented the closure policy targeted at small coal mines in order to help the state owned coal mines to get out of the difficult situation.

The closure policy itself is very strong measurement, that is command and control, which should be avoided if possible. However, for this time, several reasons can be pointed out to justify the use of command and control measurement. That's because, while town and village coal mines provided coal at lower prices than the state key coal mines, they also caused severe externality issues such as the destructive exploitation of the natural resources, environmental pollution, and frequent fetal accidents. Those externality issues could not be resolved by applying the market mechanism or through the economic incentives (Horii [2000], Horii [2001]). However, it would not be wise to shut down all the small coal mines and it would be better to take different measures to different small coal mines. As in reality, to a certain extent, comparing to the state key coal mines, the operational efficiency in small coal mines was higher. It is necessary to shut down those small coal mines that caused externality issues and create an environmental in which the market mechanism could play out its function. Based upon that, let the market mechanism to fully play out its functions, eliminate the inferior through market competition.

If the small coal mines that caused increasingly more severe externality issues were eliminated and the market mechanism could play out its roles amongst the coal mines, the price of raw coal would go up and the various policies aiming at promoting the CCTs would also be implemented. At the moment, although there is a pollution charge system called "pollutant emission fee", due to the fact that the market mechanism was not functioning in the existing coal distribution market in China, no real results could be achieved by those measures. Therefore, it is important to realize that the reason was that there had not been an environment in which the market mechanism could play out its functions.

3.3 Combine the various CCTs based upon the specific situations

It is quite possible that the dual coal distribution structure might continue even after relevant measures were taken to let the market mechanism play out its functions in the coal market in China. As stated earlier, except for the externality issues that had played a major role in maintaining that dual distribution structure, there were also other issues, such as the insufficient transportation infrastructure, and the immaturity of information intermediary, that did not support the full functioning of market mechanism. Therefore, at least within a short to medium term, it would be necessary to consider the diffusion of CCTs under the background of the dual structure of the coal distribution system in China.

As what have been summarized in section 1, there were a great variety of CCTs with varying costs and benefits, which were determined by different characteristics of the technologies were relatively low, its effects were also rather limited. Therefore, for the larger coal users, it would be better to bring in flue gas dust precipitation facilities or de-sulfurization facilities that could produce better energy conservation results and better pollution prevention results. On the other hand, to those small users that don't have sufficient capital to invest in new pollution prevention equipment, such decentralized CCTs like coal washing and briquette technologies might help them to better balance costs and benefits. Perhaps, in the areas where high-sulfur content coal was produced, it might be necessary to bring in CFBC facilities. Therefore, it's important that coal mines or coal users should not be forced to apply a specific CCTs technology. Instead, various CCTs should be offered to the users based upon the actual situation and let the users choose the type of technology that could bring about the best cost and benefit results by themselves.

As the quality of coal consumed in different areas vary a lot, the CCTs preferred in different areas might also be quite different. However, based upon the general situation in the country, the following ideal model might be proposed. That is, within the coal distribution system from small coal mines to small users, introduce the decentralized CCTs, such as coal washing and briquette technology. On the other hand, within the coal distribution system from large coal mines to large coal users, introduce centralized CCTs including CWM, flue gas dust precipitation facilities and de-sulfurization facilities. Thus the emission of pollutants in the whole society would be minimized. Of course, in terms of cost, such a practice would only add low costs to the former and it would be rather unfavorable to the latter. Therefore, it is necessary to offer economic incentives to eliminate the unfair competitive conditions. More specifically, for instance, a certain fee based upon the volume of SO_2 emission by the former could be collected, which could be provided to the latter as a compensation for their application of de-sulfurization facilities. In fact, the existing "pollutant emission fee" should have played such a function. However, it had failed because it was difficult to monitor the emission, and the charging standard was too low. Therefore, based upon the current level on pollutant emission monitoring, it would be out of the question to evaluate the effects brought about by the various CCTs applied by each user.

3.4 The environmental protection measures should be based upon the overall coal distribution

Maybe Chinese government had realized the existing "pollutant emission fee" system had failed to bring good results, and since 1998, China has started to implement the so-called "two controlled zones" policy, aiming at preventing air pollution. The two controlled items referred to acid rain and SO_2. The details of the policy was that the government had defined the areas with severe acid rain and SO_2 pollution as controlled was prohibited to explore coal that contains more than 3% of sulfur. The new coal mines that produce coal that contains over 1.5% sulfur and the coal mines that produce coal that contains above 2% sulfur, or coal in which the inorganic sulfur exceeded half of the sulfur content, were obligated to install coal washing facilities, (2) The power plants that consumed coal with over 1% sulfur content were obligated to install flue gas de-sulfurization facilities, (3) In urban areas, reduce the proportion of direct coal combustion and increase the proportion of gas and power consumption, (4) Implement the "pollutant emission fee" system and increase the charging standard (Li, [1999]).

However, from the perspective of overall coal distribution, there were some issues in those measures. Of which, measures (3) and (4) were basically fine, however, from the perspective of minimizing the pollutant emission in the whole society by least cost, measures (1) and (2) seemed to be not so appropriate. Firstly, regarding measure (1), even for coal that contains over 3% sulfur, as long as the users have installed the de-sulfurization facilities, it would not matter even if the sulfur content were higher. On the contrary, in order to reduce the operational costs of de-sulfurization facilities, it would be necessary to expand the production volume of gypsum, a byproduct. Under such a situation, the operational efficiency would be even better if coal that contained certain level of sulfur were used. As to measure (2), it implies that it was not necessary for power plants that consume coal that contains less than 1% sulfur to install the de-sulfurization facilities. That is opposite to the ideal model for the diffusion of CCTs as mention earlier, which is to have large coal users with the financial capacity to apply CCTs that cost more with better results.

In addition, there could be an even more serious problem. That is, under such a situation, since power plants, as large coal users, would concentrate on purchasing coal with low sulfur content, it might result in the deterioration of coal quality provided to such small coal users as industrial and household boilers. If that happens, there would be a ironical situation that small users, where no pollution abatement measures were introduced, would consume low quality coal, and large coal users, which had supposed to control pollutant emission through pipe-end pollution treatment facilities, would consume high quality coal. Therefore, one conclusion could be drawn that, the implementation of the "two controlled zones" policy would not be able to achieve its target of minimizing pollutant emission with least costs.

More flexible measures were needed to solve this problem. On the one hand, provide low sulfur content coal that has gone through coal washing and briquette process to the small coal users. And on the other hand, have flue gas dust precipitation facilities and de-sulfurization facilities installed by the large coal users, and allow them to consume high sulfur content coal with over 3% sulfur content[9]. In reality, such a coal flow would not occur by itself. Therefore, certain economic incentives would be necessary. For instance, while supplying coal to consumers, the coal mines might add certain taxes or fees to the coal prices based upon the pollutant content in coal. Take the example of sulfur, if certain taxes or fees on the sulfur content were to be included in the coal price, the price of coal that has gone through coal washing or briquette process would be lower comparatively, since it would contain less sulfur. The price of raw coal would be higher comparatively as it has higher sulfur content. Under such a situation, small coal users would naturally opt for lower priced coal that has gone through coal washing or briquette processes. For the large coal users, even if they consume more expensive raw coal with higher sulfur content, as long as they have installed the de-sulfurization facilities, it would still be acceptable to them as they could obtain refund for their investment for the de-sulfurization facilities[10]. The advantage of this policy is that, by allowing the coal mines or coal users to choose the CCTs by themselves, it could achieve the maximum reduction of pollutant emission in the whole society at minimum costs. In addition, in terms of monitoring, the government would not have to monitor all the hundred of thousands of coal users, instead, it would only be necessary to monitor the tens of thousands of large coal mines (of course the number is still very remarkable). The author believes that through this way, to a certain degree, it might help to resolve the problems in the implementation of environmental restrictions as have been pointed out earlier.

3.5 Combine the CCTs deployment with the industrial restructuring, which is ongoing at the moment, and obtain the synergy effects

The current restructuring of the coal industry and power industry in China would also have big impacts on the promotion of CCTs. Firstly let's take the example of the power industry. At the time being, China's power market is being vigorously reformed. One of the radical changes has been that since the second half of 1980s and during the 1990s, the construction of power plants had more and more depended upon the investment from loan or private financing, rather than allocated grant funds by government as what had been the case under the planned economy. That measure was introduced under the

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[9] Some people felt discouraged that due to high cost, de-sulfurization facilities might not be able to be introduced to China. However, from a long term of view, if coal that contains over 3% of sulfur were forced out of the distribution, it might result in abandonment of the low cost resources, which might in the end result in even higher cost. Therefore, in addition to cost comparisons on the CCT, policy decisions should be made based upon considerations on costs over longer terms.

[10] However, it goes without saying, that in the beginning, since market mechanism was not able to play out its full function and the expected results might not be achieved. Therefore, it would be necessary to take measures to improve the transportation infrastructure and strengthen the roles of intermediaries in the

backdrop of serious power shortages. At that time, in order to best promote the development of power industry, the new pricing system for selling power to grids was adopted, under which the power plants were allowed to add a certain amount of profit in addition to all the costs for the power generation. Although such a policy had successfully attracted capital from various sectors, it also resulted in high power prices for a long time. Taking into consideration of the above situation, as currently the power shortages have been greatly alleviated, Chinese government has been trying to set up a market oriented system to let the power plants bid for priority power supply, in order to bring the prices down.

From the perspective of promoting the CCTs, there were great uncertainties in the direction of the above-mentioned reforms in the power market. That's because, at the moment, the direction of the reforms is very simple, which is only favorable to those power plants that could participate the tendering process with low prices. However, at least at this moment, it seems that not much consideration has been given to those power plants that have higher power generation costs due to the investment on CCTs, which had resulted in higher environmental protection costs. The equipment utilization rate in the thermal power plants has been decreasing over the years, from 61.6% in 1987 at its peak after 1978 to 50.1% in 1999, which shows that the environment surrounding power plants management is getting very severe in the price competition. Under such environment, most of power plants might be unwilling to promote the application of CCTs. Therefore, in promoting CCTs in China, it is necessary to establish a system that is designed to introduce the application of CCTs while promoting the reforms and restructuring in the power industry.

During the mean time, fundamental reforms are being carried out in China's coal industry, including measures on forced closure of small coal mines and the bankruptcy of state owned coal mines. In the past, raw coal had been the primary product in the coal industry, which had little added value. To a certain degree, China's coal industry was not able to grow because of the internal vicious competition. In fact, many coal mines have been in continued structural losses, even facing bankruptcy, because the added value of their products was too low. Therefore, it is necessary to change their mindsets and realize that CCTs could help them to update and upgrade the coal industry, so that they would actively take measures to apply CCTs. The application of CCTs should be complementary to the reforms in the coal industry, and thus, multiplied results could be obtained.

3.6 Strengthen the contacts and coordination with the international fund raising mechanisms

However, it could also greatly contribute to energy conservation. In order to cover the costs for the application of CCTs, it would be very helpful to pay more attention to the energy conservation benefits, furthermore its benefits on the reduction of CO_2, and actively seek to utilize such fund cooperation schemes from CDM and other organizations targeted at the prevention of global warming.

Generally speaking, those funds aimed at eliminating the emissions of greenhouse gas were less inclined to provide financial support to coal users. That's because, of all the fossil fuels, carbon content is the highest in coal, consequently, greenhouse gas emission by coal is also the highest even if advanced CCTs are used. However, for China, in order to obtain the financial support from those funds, it is absolutely necessary to let the outside world realize that deployment of CCTs have been very important in China for the sake of reducing the greenhouse gas emissions. The reasons are the following. Firstly, in the time to come, China's coal consumption would be growing along with the ever-increasing overall energy demand in China. Under such a background, the result on the reduction of greenhouse gas emission that could be achieved by promoting CCTs should by no means be overlooked. Secondly, although as a byproduct of CCTs application, the reduction on the emissions of pollutants including coal dust and SO_2 is not a global issue, still it could bring great benefits on the local level. Therefore, to the relevant international funds, it deserves certain considerations.

Earlier the author has pointed out that more ways need to be worked out in order to obtain synergy effects through the updating and upgrading of coal industry as well as the promotion of CCTs applications. In promoting CCTs in China, it is very important to try to obtain financial support from the international fund cooperation schemes. For those coal mines facing continued operational difficulties, they could revive their business operations by taking advantage of those schemes to raise the necessary funds.

Conclusion

In the beginning of this article, the author has pointed out that, for such a large coal producer as China, CCTs could play an even more important role than in other countries. Within Chinese government there had formed a common understanding regarding the importance of CCTs, and the commercialization of CCTs had been included in China's 10^{th} five-year plan as one of the key pollicies for the coal industry. The details are the following. (1) Renovate and build new coal washing factories, (2) Introduce mixed coal by building coal centers, (3) Maturize CCTs, (4) Further develop CBM (coal bed methane) technology, (5) Promote the development and application of coal liquefaction and coal gasification technologies. However, the above guidelines clearly show that quite similar to previous measures aimed at promoting CCTs, those guidelines were more focused on technological development and provided little policy support to the diffusion of CCTs. That could be best demonstrated by the policy on coal washing technology, which had been elaborated in this article as one of the key issues. In the 10^{th} five-year plan, it was requested that large and medium sized coal mines should set up coal washing factories. As to coal produced by the small coal mines, it was supposed to be washed in the coal washing factories under the large coal mines, or be washed in centrally constructed coal washing factories for the small coal mines. Here, we could not see any soft measures aimed at addressing the excessive production capabilities and the declining operating rate in the existing coal washing factories, issues that have been discussed in this article. Neither are there any measures aimed at promoting the diffusion of coal washing technologies.

In this article, we have discussed issues related to the diffusion of CCTs, the existing problems and the type of policy support that was necessary to resolve those problems. The key point of this article is that, based upon the understanding of the actual coal distribution system in China, it is clear that it was not the technical constraints that had affected the diffusion of CCTs in China. Instead, it was more constrained by economic or social factors. To remove those constraints, more soft measures were needed, including strengthening the market mechanism, intensifying the implementation of environmental laws and regulations, combining the promotion of CCTs with the industrial restructuring and obtain the multiplied effects, and strengthening cooperation with the international fund schemes. The author believes that as more and more attention would be given to the application of CCTs in the future, there would be more research and discussion on this subject. Furthermore, while considering cooperation with China on CCTs projects, the various countries including Japan should all share the same point of view. In the past, while other countries cooperated with China on CCTs projects, more attention was given to hardware support. In the future, this might be changed and it would be more and more important to provide support on the software.

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